QUATERNARY RESEARCH 33, 219–230 (1990)

Younger Dryas Climatic Reversal in Northeastern USA? AMS Ages for an Old Problem

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Received November 28, 1988

Late-glacial macrofossils from a 10-m core from Alpine Swamp, New Jersey, were radiocarbon dated using accelerator mass spectrometry (AMS). The arrival of the first trees to the area following deglaciation is indicated by maximum percentages of spruce pollen and a date of 12,290 ± 440 yr B.P. on a single spruce needle. Subsequent spread of deciduous hardwoods was followed by the expansion of boreal taxa, including spruce (*Picea*), fir (*Abies*), larch (*Larix laricina*), paper birch (*Betula papyrifera*), and alder (*Alnus*). Three AMS dates on paper birch seeds and a spruce needle during this boreal expansion indicate that it took place between 11,000 and 10,000 yr B.P. The timing of this vegetational shift and its correlation with late-glacial pollen stratigraphy from many sites in southern New England indicate that a climatic reversal correlative with the Younger Dryas characterized the North Atlantic seaboard of the United States.

INTRODUCTION

Establishing the geographic distribution of specific climatic events is essential for understanding the mechanisms and causes of climatic change. The transition from the last glaciation to the present interglaciation is particularly intriguing because of an unexpected and dramatic return to cold conditions, which occurred even as Northern Hemisphere summer insolation increased (Berger, 1978). This Younger Dryas stade, approx 11,000–10,000 yr B.P., is clearly documented in data from Europe (Lowe *et al.*, 1980; Watts, 1980), Greenland (Dansgaard *et al.*, 1982), eastern Canada (Mott *et al.*, 1986a, b) and the North Atlantic (Ruddiman and McIntyre, 1981; Broecker *et al.*, 1988). Correlations with cooling events in the mid-continental United States (Shane, 1987), southern South America (Heusser and Rabassa, 1987), the Antarctic (Jouzel *et al.*, 1985), and the North Pacific (Mathewes, 1987; Keigwin and Jones, 1988) suggest a possible worldwide climatic event.

Whether or not this climatic reversal is reflected by the pollen stratigraphy of southern New England has been debated for almost half a century. We discuss the reasons for this controversy concerning northeastern North America, including the following questions: (1) Is there a consistent pollen stratigraphy present in southern New England? (2) Does this pollen stratigraphy indicate that a climatic reversal took place? (3) Is this reversal correlative with the Younger Dryas? We present new pollen, macrofossil, and radiocarbon evidence from Alpine Swamp, New Jersey, that indicates that such a cooling indeed was experienced in the northeastern United States.

BACKGROUND

Indications of a late-glacial climatic reversal in the United States were first described about 50 years ago and reinforced by subsequent investigations (Deevey, 1939; Leopold, 1956; Deevey, 1958; Ogden, 1959). The typical southern New England

0033-5894/90 $3.00

late-glacial pollen stratigraphy (Davis, 1967) is a tripartite sequence. An initial herbaceous tundra pollen zone "T" is eventually succeeded by a spruce–hardwood zone "A-3" with thermophilous species such as oak (*Quercus*) and ash (*Fraxinus*). Subsequent percentage decreases of these deciduous species are accompanied by increases in boreal species such as spruce (*Picea*), fir (*Abies*), larch (*Larix*), birch (*Betula*), and alder (*Alnus*) (denoted by the A-4 spruce zone). Later, the hardwoods again increase, along with pine (the B zone).

The northeastern U.S. pollen stratigraphy alone indicates that the same major shift in species took place at more than 15 sites, providing a regional signature (Peteet, 1987). Typical stratigraphic sections that exhibit this late-glacial pattern of reversal include Rogers Lake, Connecticut (Davis, 1969, 1983), and Linsley Pond, Connecticut (Deevey, 1939). Gaudreau and Webb (1983) note that a spruce peak characterizes the A-4 zone at many sites, but a climatic interpretation is not invoked. Although the pattern is widespread in southern New England, the apparant absence of the oscillation in some northern New England sites (Davis and Jacobson, 1986) remains puzzling; however, these sites are characterized by very low sedimentation rates.

This palynological oscillation has been enigmatic because of difficulties in interpreting vegetational changes from the pollen zones A-3 to A-4 and their timing. Although early interpretations invoked a major vegetational change resulting from a climatic cooling (Deevey, 1939; Leopold, 1956), the subsequent consideration of pollen influx (accumulation rates of individual pollen taxa) from Rogers Lake, Connecticut (Davis and Deevey, 1964; Davis, 1967a, b), prompted a rejection of this hypothesis. Davis (1967a, b) interpreted the A-3 spruce–hardwood zone as reflecting a tundra–conifer landscape because hardwood pollen accumulation values were low. She suggested that the apparent decline of the warmth-demanding hardwood trees actually represented a dilution of the hardwood pollen, resulting from long-distance transport, by local increases in conifer pollen resulting from forest expansion caused by gradual warming. Davis also used a 730-year correction for radiocarbon dates (now rejected: Davis, 1983) which placed the time of this oscillation after 10,000 yr B.P. Thus, the palynological oscillation was considered a percentage artifact and the corrected chronology incompatible with a possible Younger Dryas event in the northeastern United States. This conclusion has been widely accepted (e.g., Watts, 1983) but needs re-evaluation.

The critical factor in determining whether this palynological shift is correlative with the European Younger Dryas is the chronostratigraphy. At many sites, radiocarbon control suggests that the reversal occurred 11–10,000 yr B.P. (Davis, 1983; Peteet, 1987), but bracketing dates are often either lacking or not closely constraining; furthermore, available dates are solely from bulk organic sediment samples that possibly are contaminated with older or younger carbon (Lowe *et al.*, 1988). Alpine Swamp, New Jersey, is one of several sites selected to refine the pollen stratigraphy and to provide macrofossils that can augment the vegetational reconstruction and provide identifiable material for radiocarbon dating by accelerator mass spectrometry (AMS).

STUDY AREA

Alpine Swamp (40°58'N, 73°55'W) (Fig. 1) is located in northeastern New Jersey at 150 m altitude atop the Palisades Sill about 4 km west of the Hudson River. The area was deglaciated possibly as early as 18,000 yr B.P., based on bulk radiocarbon dates from basal Francis Lake silts, north of the terminal moraine (Evenson *et al.*, 1983). Natural forests of the region are classified as oak–chestnut (Braun, 1950), with sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), yellow birch (*Betula lutea*), and hemlock (*Tsuga canadensis*) regionally present. Within this mixed hardwood forest

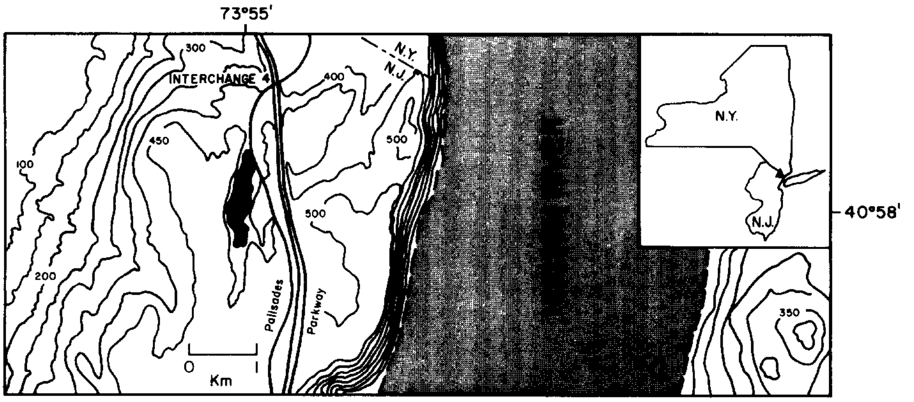

FIG. 1. Map showing location of Alpine Swamp, New Jersey (adapted from U.S. Geological Survey 7.5′ Yonkers Quadrangle).

the 9-ha swamp is locally characterized by red maple (*Acer rubrum*) and black ash (*Fraxinus nigra*).

METHODS AND RESULTS

Two sediment cores (A and B) were retrieved with a modified Livingstone piston corer (Wright, 1967). Pollen was obtained from 1-ml samples taken at 10-cm intervals in core A and at 5-cm intervals in core B. Sample processing followed Faegri and Iversen (1975) and Cwynar *et al.* (1979); at least 300 grains/sample were tallied. Calibrated *Eucalyptus* tablets were added to the samples to calculate pollen influx (Maher, 1972). Samples were processed for macrofossils in core B following the procedure of Birks (1976). AMS-dated macrofossils were subjected to the normal acid/alkali washes and were combusted with CuO in sealed quartz tubes. Samples, in the 48- to 78-μg size range, were combusted to CO_2 and measured. These samples are small even by AMS standards, and the relatively large resulting standard deviations arise from uncertainty in the background to be subtracted due to contamination during processing (Vogel *et al.*, 1987). The measurements were made as described by Nelson *et al.* (1986).

Figures 2 (Core A) and 3 (Core B) illustrate the major arboreal species represented by the pollen percentage stratigraphy, which is very similar to the stratigraphy in Rogers Lake (Davis, 1967) and Linsley Pond (Deevey, 1958). The typical sequence of relative decreases of the hardwoods—oak, ash, and hornbeam (*Ostrya–Carpinus*)—are accompanied by concurrent increases in spruce, fir, larch, birch, and alder. Conventional radiocarbon dates (Table 1 and Fig. 2) of bulk sediment indicate an age of between 12,000 and 10,000 yr B.P. for the A-4 interval. The influx diagram (Fig. 3) demonstrates that changes in the composition of species are not simply an artifact of percentage computation. Spruce, fir, larch, birch, and alder all show independent increases in the A-4 zone, while oak declines.

A second adjacent core (B, Fig. 4), was subsequently retrieved in order to determine the macrofossil stratigraphy within the swamp (Fig. 5) and the age of specific macrofossils from the A-4 interval. The palynological sequence in this core is equivalent to that of core A, although the A-4 interval occurs from 8.25 to 9 m depth. Spruce and larch needles are found in the A-3 pollen zone, indicating that these trees were locally present at 12,300 yr B.P. (Table 1), prior to their expansion in the subsequent A-4 zone. The A-4 zone contained spruce needles, one spruce seed, larch needles, and paper birch (*Betula papyrifera*) seeds, indicating that these plants were locally present. The specific identification of

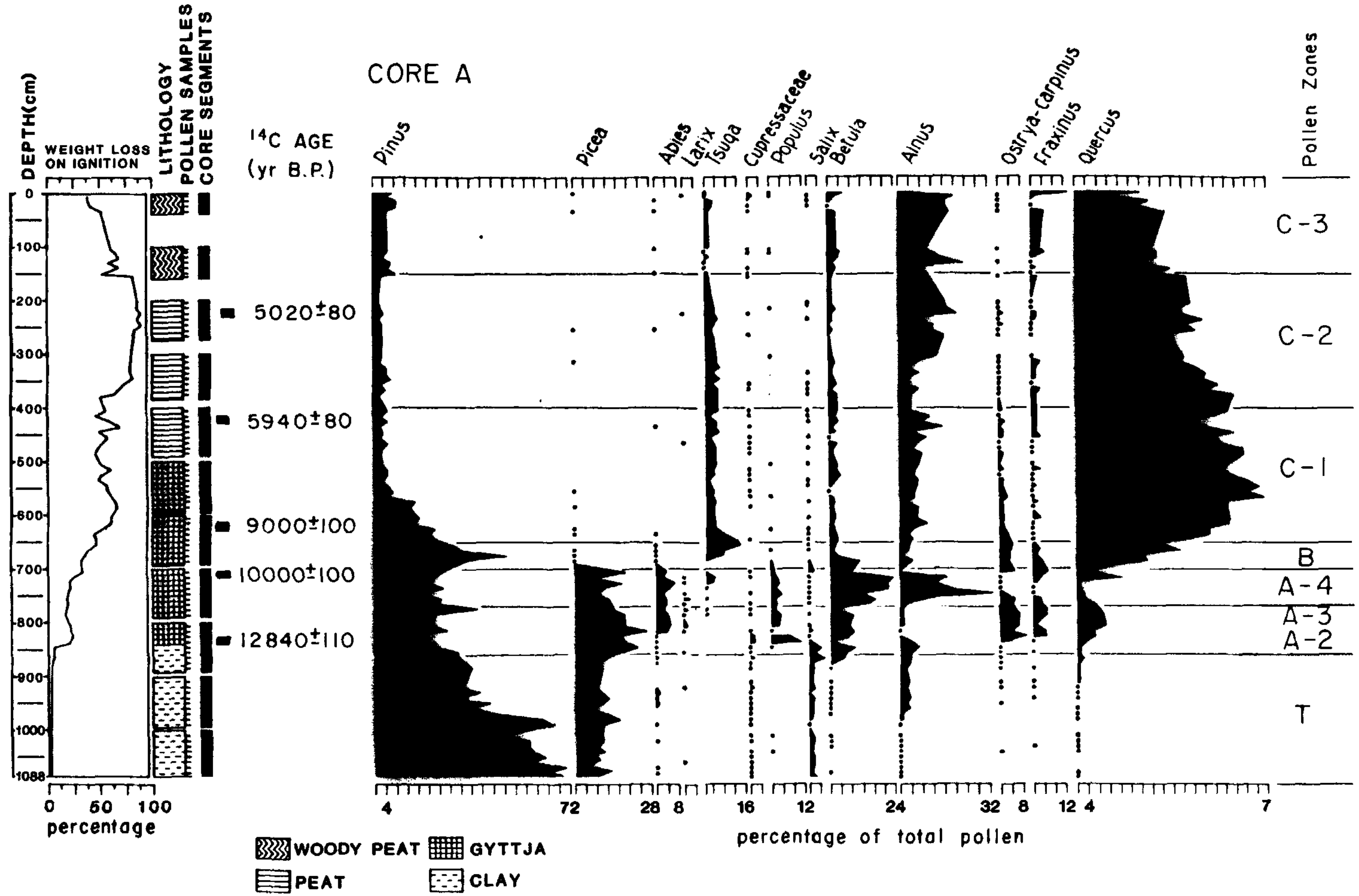

FIG. 2. Simplified pollen-percentage diagram from Core A, Alpine Swamp, New Jersey. Increases in percentage of boreal trees during the A-4 pollen zone suggest a climatic cooling. Conventional ^{14}C dates on bulk organic samples indicate that the cooling occurred sometime after 12,000 yr B.P. and before 10,000 yr B.P.

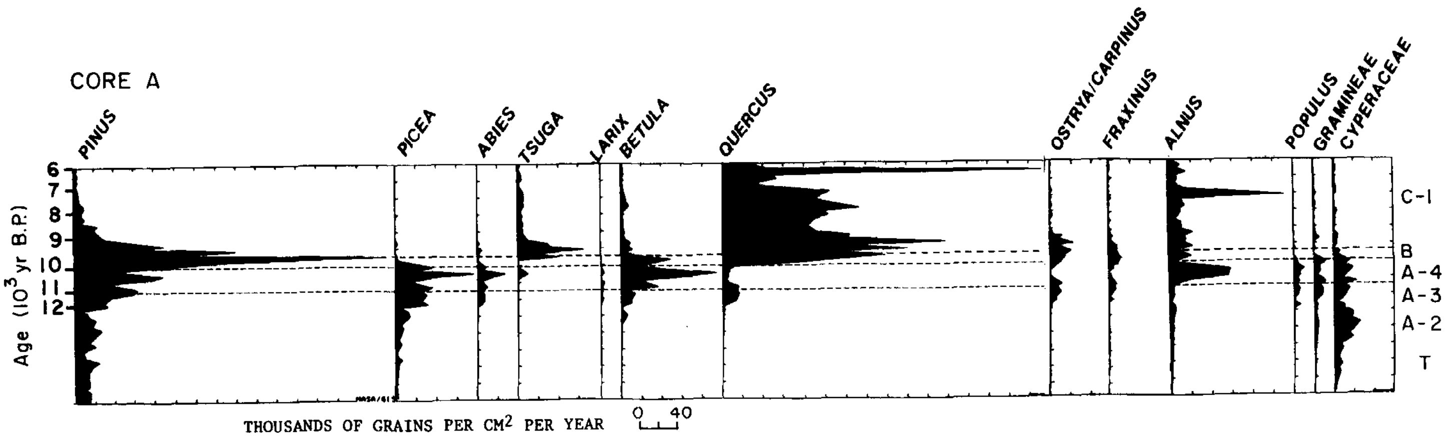

FIG. 3. Pollen influx diagram of selected species from Core A, Alpine Swamp, New Jersey. Independent boreal species increases during the A-4 pollen zone suggest that a climatic cooling took place approximately 11,000–10,000 yr B.P.

TABLE 1. CONVENTIONAL AND ACCELERATOR MASS SPECTROMETRY ^{14}C DATES OF ALPINE SWAMP SAMPLES[a]

A. Conventional ^{14}C dates of bulk organic sediment from Core A

Lab no.	Sample interval (cm)	^{14}C age
WIS-1464	207–213	5020 ± 80
WIS-1465	407–413	5940 ± 80
WIS-1466	607–613	8980 ± 100
WIS-1481	707–713	10,000 ± 100
WIS-1482	825–832	12,840 ± 110

B. AMS dates on identified macrofossils from Core B

Lab no.	Sample interval (cm)	Identification	Size (μg)	^{14}C age (yr B.P.)
RIDDL 815	825–830	2 *Betula papyrifera* seeds	52	10430 ± 380
RIDDL 817	855–860	1 *Picea* needle	78	10230 ± 220
RIDDL 819	875–880	5 *Betula papyrifera* seeds	48	10470 ± 440
RIDDL 1136	990–995	1 *Picea* needle	105	12290 ± 440

C. Unidentified woody fragments

Lab no.	Sample interval (cm)	Size (μg)	^{14}C age (yr B.P.)
RIDDL 816	825–830	225	619 ± 100
RIDDL 818	855–860	120	3860 ± 120
RIDDL 820	875–880	160	3490 ± 110

[a] The $\delta^{13}C$ values of macrofossils and wood are assumed to be −25‰.

paper birch is significant, as this cold-climate species now extends northward across Canada and Alaska almost to the limit of tree growth (Fowells, 1965). The number of these macrofossils decreases in the subsequent B zone, from which a single white pine needle (*Pinus strobus*) was recovered.

The three AMS ^{14}C ages on macrofossils from the A-4 interval place the dominance of paper birch and spruce between 11,000 and 10,000 yr B.P. (Table 1). The large 1 σ errors associated with the dates reflect the difficulty in determining the age of small samples, but even with the uncertainty, the boreal dominance from all three samples falls within the millennium in question. AMS dates of tiny unidentified woody fragments from the same interval are all significantly younger than the dates of bulk organic sediment or of the identified boreal macrofossils. The younger age of the woody fragments suggests their introduction into older sediments during the coring procedure. A mixture of both identified and unidentified materials would have yielded a spurious date for the interval. Thus, it is critically important to date identifiable plant remains so that contextual relevance can be judged (Jackson *et al.*, 1986). In this instance, the climatic indicators (boreal macrofossils) are the material dated and questions of association do not arise because these taxa are not in the modern flora.

DISCUSSION

The interpretation of palynological records requires determining whether the palynological shifts represent actual vegetational change and if so, deciphering the possible causes of these vegetational

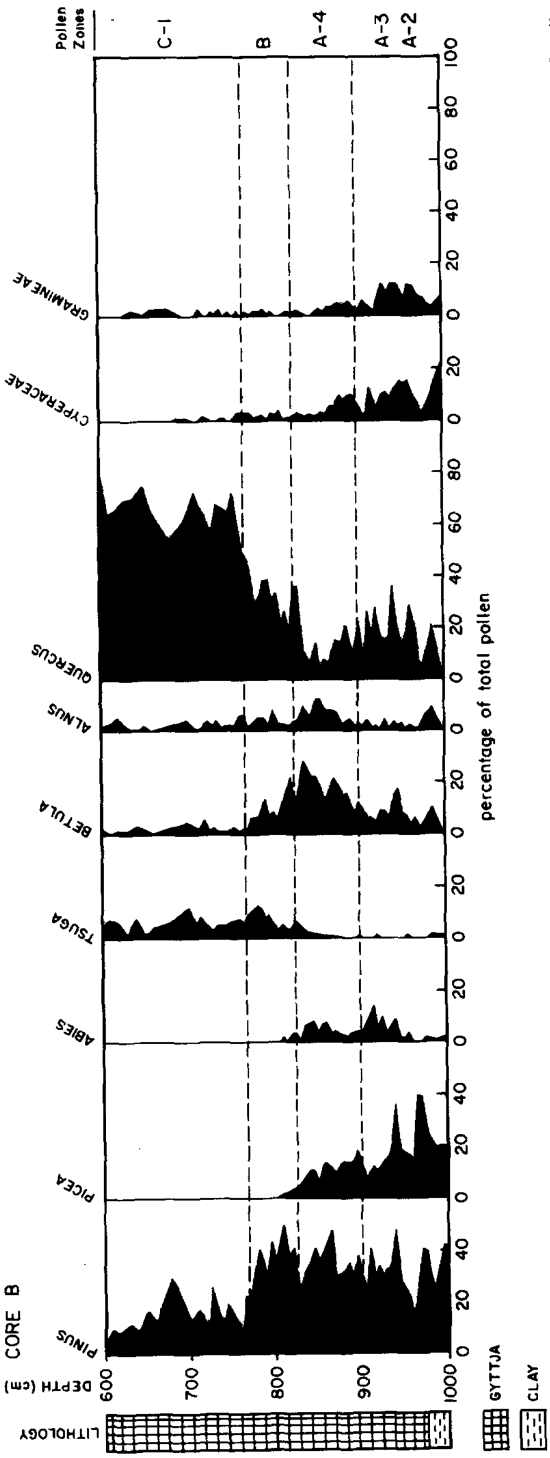

FIG. 4. Simplified pollen-percentage diagram from Core B, Alpine Swamp, New Jersey. This core was taken primarily for late-glacial macrofossil analysis; the pollen stratigraphy shows the same late-glacial stratigraphic pattern as in Core A.

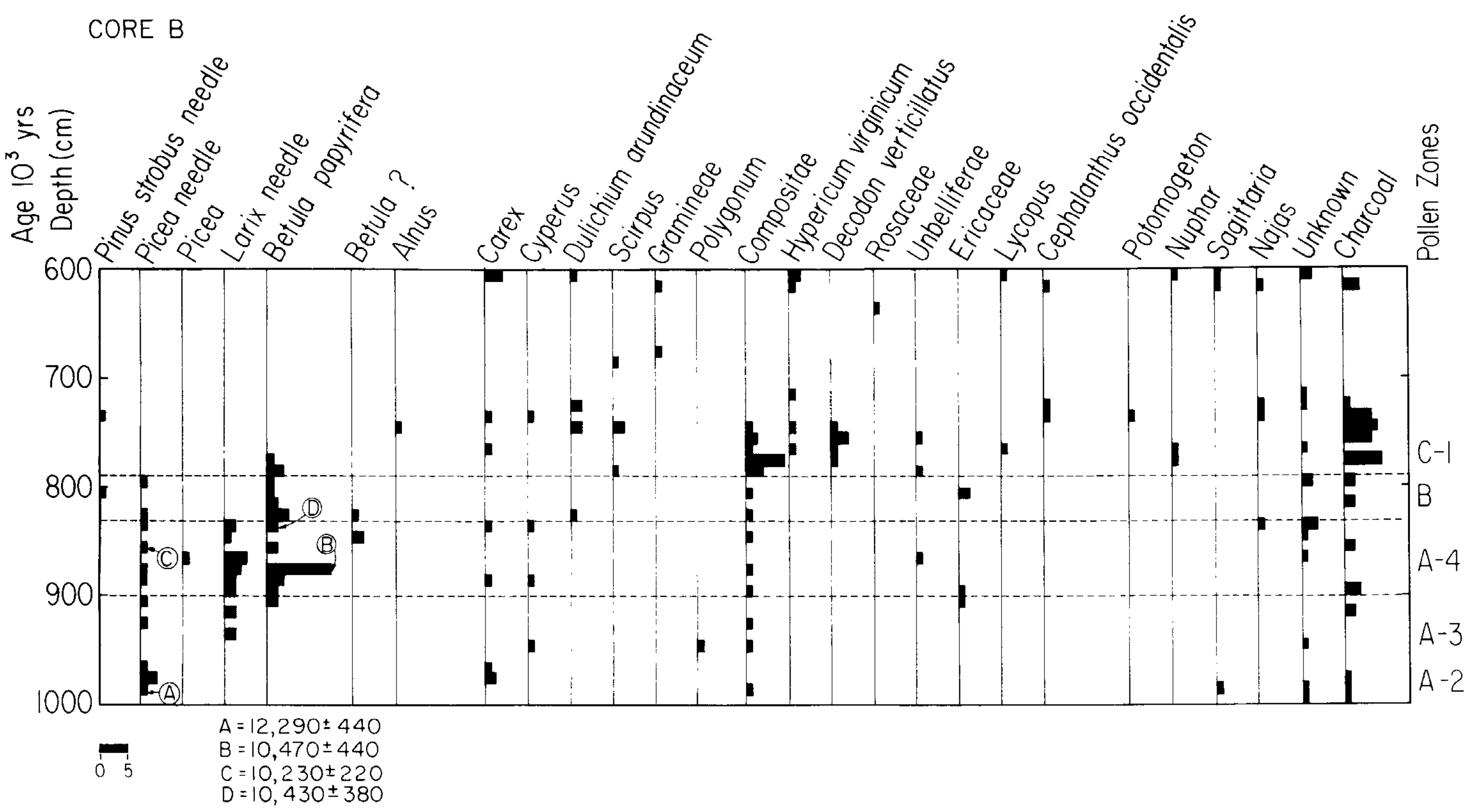

FIG. 5. Macrofossil diagram of lower portion of Alpine Swamp, New Jersey, sampled from 50 cc at 5-cm intervals. The presence of spruce (*Picea*) and larch (*Larix*) needles prior to the A-4 zone indicate their local presence. AMS dates on boreal macrofossils in the A-4 zone all are between 11,000 and 10,000 yr B.P. (Table 1). Unless specified otherwise, macrofossils represent seeds.

changes. The large number of sites in New England which reveal the typical A-4, A-3, B stratigraphy suggests that a late-glacial vegetational change took place, and that the spruce–hardwood zone at Alpine Swamp was actually composed of hardwoods (i.e., oaks) within 10 km of this site; today the 5% oak isopoll lies south of the northern limit of oak trees (Davis and Webb, 1975). Pollen accumulation rates from Rogers Lake (Davis, 1967a, b) and Alpine Swamp (Fig. 3) indicate that the A-4 hardwood pollen decline was independent of the much larger boreal forest expansion. Argument for long-distance transport of the hardwood pollen based on the quantity of grains present is tenuous, because pollen accumulation rates vary widely both within and between depositional basins (Pennington, 1973) due to such factors as variations in pollen recruitment processes and sediment focusing (Davis and Ford, 1982). The presence of local species is best confirmed by macrofossils, but thus far few studies have emphasized macrofossil research, and as yet no hardwood seeds have been recovered from the A-3 zone.

Edaphic, competitive, and successional factors are all local reasons for a vegetational change, and are primarily short-term effects. In contrast, pyric, migrational, and climatic factors are regional determinants of vegetational change. The large number of sites in southern New England with this similar palynological stratigraphy implies a regional cause for the inferred vegetational change. While fire undoubtedly influenced the late-glacial landscape of New England, charcoal data from Alpine Swamp (Fig. 5) do not indicate an increase in fire during the A-4 pollen zone. Charcoal data are not available from most other sites; thus, an assessment of the pyric role in regional vegetational reconstruction awaits further analysis.

Two major obstacles exist to interpreting the observed New England palynological shift as due to migration. The first is the *apparant* large rapid latitudinal distribution of such a shift, from Maine (Jacobson *et al.*, 1983) and New Hampshire (Davis, 1983) south to New Jersey, between 11,000 and 10,000 years ago. Figures 2 and 3 show that the increase in spruce, fir, alder, and birch coincides with the oak decrease in northern New Jersey. Pollen influx, as well as percentage values, from New Hampshire (Davis, 1983) and Connecticut (Davis, 1983) indicates that boreal types also increased during the 11,000–10,000 yr B.P. interval at these widespread sites. An expansion of boreal taxa, if synchronous throughout 5° of latitude, implies a nonlocal cause. However, few other published New England sites are available for a rigorous assessment of the timing of the late-glacial stratigraphy.

The second obstacle to accepting a northward migration in the region due to gradual warming is that in New Jersey (this study), Connecticut (D. M. Peteet, unpublished data), Pennsylvania (Watts, 1979), Vermont (Miller and Thompson, 1979), and Nova Scotia (Mott *et al.*, 1986b) spruce needles are present in sediments well below the A-4 boreal zone. These needles mark the establishment of spruce in the region prior to 11,000 yr B.P. (as early as 12,300 yr B.P. in Alpine Swamp). Spruce and fir are found as macrofossils in the A-3 interval at Tannersville Bog, Pennsylvania (Watts, 1979), and expand along with larch and paper birch in the A-4 zone, just as they do in Alpine Swamp. These genera all appear in the pollen percentages below the A-4 zone and thus were regionally present. Their sudden increase therefore must not be the result of migration, but rather the response to an abrupt environmental change, most probably climatic in nature. However, the precise nature of this change, and its magnitude, is not clear.

Increases in seasonality during late-glacial time in the northeastern United States suggest that vegetation experienced summers at least as warm as today, although winters were more severe (Rind *et al.*, 1986). The sudden shift to A-4 species dominance implies colder, snowier conditions, because spruce, fir, larch, and paper birch all have distributions today at northern latitudes and high altitudes (Fowells, 1965). Climatic data from the boreal forest in the Adirondack Mountains, northeastern New York, indicate that altitudes above 400 m are 3°–4°C cooler and receive more snow than those near sea level (NOAA, 1974). Today these higher altitudes are characterized by a boreal suite of trees, whereas lower altitudes support oak, ash, pine, yellow birch, maple, and hemlock (Fowells, 1965). If summers became colder or shorter during the Younger Dryas interval, these northern species would likely have outcompeted oak, ash, and hornbeam. Extreme winters with deeper snow and/or increased ice storms may have created gaps in the mixed conifer–hardwood forest during the A-4 interval, which were then filled by light-demanding paper birch and alder. At higher elevations, alder may have replaced spruce at timberline, due to soil instability or wetter environments from persistent snow cover. As the boreal species declined at the close of A-4 (10,000 yr B.P.), increases in alder in some sites (i.e., Gaudreau and Webb, 1985) may have been a successional phenomenon, filling in the gaps before the nearby hardwoods and pine expanded dramatically.

Inferring climatic cooling from the increase in a suite of boreal species is not unique to this pollen record. The Upper Pleistocene pollen record from Lyon, France (de Beaulieu *et al.*, 1984) exhibits the same generic oscillations during the Middle Würm interval (ca. 60,000–30,000 yr B.P.). Temperate phases with oak and hazel alternate with colder intervals of birch, spruce, fir, and alder. Although the European species are different from the North American species, the climatic implications are the same.

CONCLUSION

The striking consistency in late-glacial pollen stratigraphy in the northeastern United States, first recognized in the 1930s, strongly suggests that a vegetational reversal occurred regionally. Bulk radiocarbon dates generally place the timing of the reversal, including a major spruce peak, at approximately 11,000–10,000 yr B.P. AMS radiocarbon ages of macrofossils provide tangible evidence of the expansion of boreal taxa at Alpine Swamp, New Jersey, during this interval. The identification of boreal species expansion and their rapid demise at 10,000 yr B.P. suggests that the Younger Dryas climatic cooling was responsible for the vegetational change.

The demonstration of a North American vegetational response to the Younger Dryas cooling along the North Atlantic seaboard and in regions away from the North Atlantic basin (Shane, 1987) raises further questions concerning the origin of this event. Changes in ocean circulation resulting from a Laurentide meltwater diversion to the North Atlantic (Broecker *et al.*, 1988) could plausibly affect climate and vegetation in regions far from the Atlantic Basin. However, in most of the U.S. late-glacial stratigraphy, a palynological oscillation has not been documented. A reassessment of the palynological data would be useful because of the many factors which affect detection of rapid oscillations. These include sample selection, adequate chronological resolution, and the topographic and phytogeographic setting of the location. As one example, a lack of vegetational ecotones near a site limits the sensitivity of a vegetational response to a climatic oscillation.

The results presented in this study suggest that continuous re-evaluation and investigation of late-glacial pollen stratigraphy in North America and worldwide are important, particularly with regard to chronological control. If we are to establish the timing of changes in ocean, land, and atmosphere, AMS ages with small standard errors are needed. Firm establishment of the extent of this climatic reversal in North America may also enlarge our understanding of the contributing roles of climate and man in the late-glacial North American mammalian extinction records centered between 11,000 and 10,000 yr B.P. (Bonnichsen *et al.*, 1987).

ACKNOWLEDGMENTS

We thank C. Charles and T. Janecek for coring assistance; E. G. Bard, W. C. Broecker, C. J. Heusser, G. Kukla, M. Prather, and D. Rind for comments on the manuscript; and Jose Mendoza and Lilly Del Valle for drafting. Research was supported by NSF Grant ATM-8604397 to Columbia University and by NSERC grants to Simon Fraser and McMaster Universities.

REFERENCES

Berger, A. (1978). Long-term variations of daily insolation and Quaternary climate change. *Journal of Atmospheric Science* 35, 2362.

Birks, H. J. B. (1976). Late-Wisconsinan vegetational history at Wolf Creek, central Minnesota. *Ecological Monographs* 46, 395–429.

Bonnichsen, R., Stanford D., and Fastook, J. L. (1987). Environmental change and developmental history of human adaptive patterns: The Paleoindian case. *In* "North American and Adjacent Oceans during the Last Deglaciation" (W. F. Ruddiman and H. E. Wright, Jr., Eds.), pp. 371–402. Geological Society of America, Boulder, CO.

Braun, E. L. (1950). "Deciduous Forests of Eastern North America." Hafner, New York.

Broecker, W. S., Andree, M., Wolfli, W., Oeschger, H., Bonani, G., Kennett, J., and Peteet, D. (1988). The chronology of the last deglaciation: Implications to the cause of the Younger Dryas event. *Paleoceanography* 3, 1–19.

Cwynar, L. C., Burden, E., and McAndrews, J. H. (1979). An inexpensive sieving method for concentrating pollen and spores from fine-grained sediments. *Canadian Journal of Earth Sciences* 16, 1115–1120.

Dansgaard, W., Clausen, H., Gundestrup, N., Hammer, C., Johnsen, S., Kristinsdottir, P., and Reeh, N. (1982). A new Greenland ice core. *Science* 218, 1273–1277.

Davis, M. B. (1967a). Pollen accumulation rates at Rogers Lake, Connecticut, during late- and postglacial time. *Review of Paleobotany and Palynology* 2, 219–230.

Davis, M. B. (1967b). Late-glacial climate in Northern United States: A comparison of New England and the Great Lakes Region. *In* "Quaternary Paleoecology" (E. J. Cushing and H. E. Wright, Eds.), pp. 11–14. Yale Univ. Press, New Haven.

Davis, M. B. (1969). Climatic changes in southern Connecticut recorded by pollen deposition at Rogers Lake. *Ecology* 50, 409–422.

Davis, M. B. (1983). Holocene vegetational history of the eastern United States. *In* "Late Quaternary Environments of the United States" (H. E. Wright, Jr., Ed.), Vol. 2, pp. 166–181. Univ. of Minnesota Press, Minneapolis.

Davis, M. B., and Deevey, E. S. (1964). Pollen accumulation rates: Estimates from late-glacial sediments of Rogers Lake, Connecticut. *Science* 145, 1293–1295.

Davis, M. B., and Ford, M. J. (1982). Sediment focusing in Mirror Lake, New Hampshire. *Limnology and Oceanography* 27, 137–150.

Davis, R. B., and Webb, T., III (1975). The contemporary distribution of pollen in eastern North America: A comparison with the vegetation. *Quaternary Research* 5, 395–434.

Davis, R. B., and Jacobson, G. L. (1986). Late-glacial and early Holocene landscapes in northern New England and adjacent areas of Canada. *Quaternary Research* 23, 341–368.

de Beaulieu, J.-L., and Reille, M. (1984). A long Upper Pleistocene pollen record from Les Echets near Lyon, France. *Boreas* 13, 111–132.

Deevey, E. S., Jr. (1939). Studies on Connecticut lake sediments. I. A postglacial climatic chronology for southern New England. *American Journal Science* 237, 691–724.

Deevey, E. S. (1958). Radiocarbon-dated pollen sequences in eastern North America. *Veroffentilichungen des Geobotanischen Institutes Rubel in Zurich* 34, 30–37.

Evenson, E. B., Cotter, J. F., Ridge, J., Sevon, W., Sirkin, L., and Stuckenrath, R. (1983). The mode and chronology of deglaciation of the Great Valley, northwestern New Jersey. *Geological Society of America Abstracts with Programs* 15, 133.

Faegri, K., and Iversen, J. (1975). "Textbook of Pollen Analysis," 3rd ed. Munksgaard, Copenhagen.

Fowells, A. A. (1965). "Silvics of Forest Trees of the United States." United States Dept. of Agriculture Handbook 271.

Gaudreau, D., and Webb, T., III (1985). Late-Quaternary pollen stratigraphy and isochrone maps for the northeastern United States. *In* "Pollen Records of Late-Quaternary North American Sediments" (V. M. Bryant, Jr., and R. G. Holloway, Eds.), pp. 247–280. American Association of Stratigraphic Palynologists, Dallas, TX.

Heusser, C. J., and Rabassa, J. (1987). Cold climatic episode of Younger Dryas age in Tierra del Fuego. *Nature (London)* 328, 609–611.

Jackson, S. T., Whitehead, D. R., and Davis, O. K. (1986). Accelerator radiocarbon date indicates mid-Holocene age for hickory nut from Indiana late-glacial sediments. *Quaternary Research* 25, 257–258.

Jacobson, G. L., Webb, T., III, and Grimm, E. C. (1987). Patterns and rates of vegetational change during the deglaciation of eastern North America. *In*

"North America and Adjacent Oceans During the Last Deglaciation" (W. Ruddiman and H. E. Wright, Eds.), pp. 277–288. Geological Society of America.

Jouzel, J., Lorius, C., Merlivat, L., and Petit, J-R. (1985). Abrupt climatic changes: The Antarctic record during the Late Pleistocene. *In* "Abrupt Climatic Change: Evidence and Implications" (W. Berger and L. Labeyrie, Eds.), pp. 235–246. Reidel, Dordrecht.

Keigwin, L. D., and Jones G. (1988). High resolution paleoclimatic change in the North Atlantic Ocean. AMQUA Abstracts, p. 24–25.

Leopold, E. B. (1956). Two late-glacial deposits in southern Connecticut. *Proceedings of the National Academy of Sciences* **42**, 863–867.

Lowe, J. J., Gray, J. M., and Robinson, J. E. (Eds) (1980). "Studies in the Late-Glacial of North-West Europe." Pergamon, Oxford.

Lowe, J. J., Lowe, S., Fowler, A. J., Hedges, R. E. M., and Austin, T. J. F. (1988). Comparison of accelerator and radiometric radiocarbon measurements obtained from Late Devensian Lateglacial lake sediments from Llyn Gwernan, North Wales, UK. *Boreas* **17**, 355–369.

Maher, L. J., Jr. (1972). Absolute pollen diagram of Redrock Lake, Boulder County, Colorado. *Quaternary Research* **2**, 531–553.

Mathewes, R. (1987). A possible Younger Dryas oscillation in western Canada? XII INQUA Congress Abstracts, 221.

Miller, N. G., and Thompson, G. G. (1979). Boreal and western North American plants in the late Pleistocene of Vermont. *Journal of the Arnold Arboretum* **60**, 167–218.

Mott, R. J., Grant, D. R., Stea, R., and Ochietti, S. (1986a). Late-glacial climatic oscillation in Atlantic Canada equivalent to the Allerod/Younger Dryas event. *Nature (London)* **323**, 247–250.

Mott, R. J., Matthews, Jr., J. V., Grant, D. R., and Beke, G. J. (1986b). A late-glacial buried organic profile near Brooksdale, Nova Scotia. *Current Research, Part B, Geolological Survey of Canada Paper* 86-1B, 289–294.

Nelson, D. E., Vogel, J. S., Southon, J. R., and Brown, T. A. (1986). Accelerator radiocarbon dating at SFU. *Radiocarbon* **28**, 215–222.

NOAA (National Oceanic and Atmospheric Administration) (1974). "Climates of the States;" Water Information Center, Inc., Port Washington, New York.

Ogden, J. G., III (1959). A late-glacial pollen sequence from Martha's Vineyard, Massachusetts. *American Journal of Science* **257**, 366–381.

Pennington, W. (1973). Absolute pollen frequencies in the sediments of lakes of different morphometry. *In* "Quaternary Plant Ecology" (H. J. B. Birks and R. G. West, Eds.), pp. 79–104. Cambridge.

Peteet, D. M. (1987). Younger Dryas in North America—Modeling, data analysis, and re-evaluation. *In* "Abrupt Climatic Change: Evidence and Implications" (W. Berger and L. Labeyrie, Eds.), pp. 185–193. Reidel, Dordrecht.

Rind, D., Peteet, D., Broecker, W., McIntyre, A., and Ruddiman, W. (1986). The impact of cold North Atlantic sea surface temperatures on climate: implications for the Younger Dryas cooling. *Climate Dynamics* **1**, 3–33.

Ruddiman, W., and McIntyre, A. (1981). The North Atlantic Ocean during the last deglaciation. *Paleogeography, Palaeoclimatology, Paleoecology* **35**, 145–214.

Shane,L. C. K. (1987). Late-glacial vegetational and climatic history of the Allegheny Plateau and the till plains of Ohio and Indiana, U.S.A. *Boreas* **16**, 1–20.

Watts, W. A. (1979). Late-Quaternary vegetation of central Appalachia and the New Jersey coastal plain. *Ecological Monographs* **49**, 427–429.

Watts, W. A. (1980). Regional variation in the response of vegetation of late-glacial climatic events in Europe. *In* "Studies in the Late-Glacial of Northwest Europe" (J. J. Lowe, J. M. Gray, and J. E. Robinson, Eds.), pp. 1–22. Pergamon, Oxford.

Watts, W. A. (1983). Vegetational history of the eastern United States 25,000 to 10,000 years ago. *In* "Late-Quaternary Environments of the United States" (S. C. Porter, Ed.), Vol. 1, pp. 294–310. Univ. of Minnesota Press, Minneapolis.

Wright, H. E., Jr. (1967). A square-rod piston sampler for lake sediments. *Journal of Sedimentary Petrology* **37**, 975–976.

Vogel, J. S., Nelson, D. E., and Southon, J. R. (1987). ^{14}C background levels in an accelerator mass spectrometry system. *Radiocarbon* **29**, 323–333.